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A HEAT METHOD FOR MEASURING THE COEFFICIENT OF SELF-INDUCTION.

BY P. G. SPALDING AND H. B. SHAW.

Presented by Professor John Trowbridge, May 9, 1894.

THE coefficient of self-induction of a coil having an iron core and traversed by an alternating current depends upon the permeability of the iron, and therefore upon the current strength, in a manner which can be seen by examining the hysteresis curves of Ewing and others.

If the coil has no iron core, its coefficient of self-induction is constant for all current strengths, and may be measured by some method where the current used is small, "Rayleigh's bridge method," for instance.

If we try to calculate the coefficient of self-induction when a coil with an iron core is subjected to an alternating current, we have a practically impossible problem; but if we regard the effects as a whole, we can measure the *effective* coefficient of self-induction for any given impressed electromotive force.

The effective coefficient of self-induction of a coil having an iron core may be defined as the equal of the constant coefficient of that coil which would give the same integral current flow as the former under the given conditions.

Let us first examine the case theoretically. Given a simple branched circuit and an impressed electromotive force which varies as the ordinate of a sine curve, we obtain the following for the values of the currents in the two branches: —

$$(1) \qquad i_1 = \frac{I\sqrt{R_2^2 + p^2 L_2^2}}{\sqrt{(R_1 + R_2)^2 + p^2 (L_1 + L_2)^2}} \sin (p t + \theta_1);$$

$$(2) \qquad i_2 = \frac{I\sqrt{R_1^2 + p^2 L_1^2}}{\sqrt{(R_1 + R_2)^2 + p^2 (L_1 + L_2)^2}} \sin (p t + \theta_2);$$

where, according to Figure 1, R_1 and R_2 are the resistances; L_1 and L_2 the constant coefficients of self-induction, in the two branches;

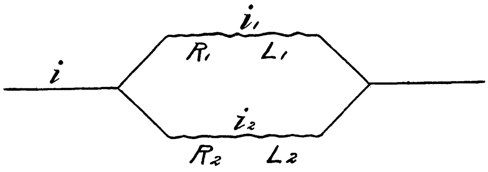

FIG. 1.

$p = 2 \pi n$; I, I_1, and I_2 are the maximum values of i, i_1, and i_2, or the square root of their mean square values multiplied by the square root of 2.* Formulæ (1) and (2) may be written

$$i_1 = I_1 \sin (p t + \theta_1),$$

$$i_2 = I_2 \sin (p t + \theta_1);$$

where

$$(3) \qquad I_1 = \frac{I \sqrt{R_2^2 + p^2 L_2^2}}{\sqrt{(R_1 + R_2)^2 + p^2 (L_1 + L_2)^2}};$$

$$(4) \qquad I_2 = \frac{I \sqrt{R_1^2 + p^2 L_1^2}}{\sqrt{(R_1 + R_2)^2 + p^2 (L_1 + L_2)^2}}.$$

Dividing (3) by (4), we obtain

$$(5) \qquad \frac{I_1}{I_2} = \frac{\sqrt{R_2^2 + p^2 L_2^2}}{\sqrt{R_2^2 + p^2 L_1^2}},$$

whence

$$L_1 = \frac{1}{p} \sqrt{R_2^2 \left(\frac{I_2}{I_1}\right)^2 - R_1^2 + p^2 \left(\frac{I_2}{I_1}\right)^2 L_2^2};$$

and if $L_2 = 0$,

$$(6) \qquad L_1 = \frac{1}{p} \sqrt{R_2^2 \left(\frac{I_2}{I_1}\right)^2 - R_1^2};$$

so that by measuring p, R_1, R_2, and $\frac{I_2}{I_1}$, we can calculate the value of L_1.

Now, considering the practical case, we see that, though the current curve is distorted by the varying permeability of the iron core and the armature reactions of the alternator, yet a definite current passes through each of the two branches, so that equations (5) and (6) still hold, though L_1 is no longer constant throughout an alternation but is the *effective* coefficient of self-induction defined above.

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* See Fleming, Alternate Current Transformer, I. 133.

The practical proof of our conclusion is an easy one. A constant L_1 is measured, first by Rayleigh Bridge and then by our heat method.

The experiment was briefly this. An alternating current was divided between two circuits, both of which had known resistances; one circuit contained a coil with no iron core whose coefficient of self-induction was to be measured; the other branch, for simplicity, had no self-induction. The ratio of the currents was determined by the amounts of heat generated in known parts of the two circuits. The connections are shown in Figure 2.

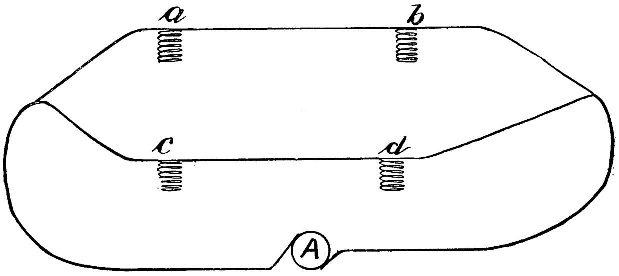

FIG. 2.

A is a suitable alternator, the one used had a frequency of 200 ~. *a* and *c* are heat coils of German silver wire wound non-inductively; the resistance of each was 1.288 ohms, and they were placed in oil in order to measure the heat generated. *b* is the coil whose coefficient of self-induction is to be measured; it had no iron core. *d* is a resistance coil, proportioned to make the currents in the two branches about equal; it was wound non-inductively and placed in oil to keep it cool. A known standard of variable self-induction might be used and would be less trouble to adjust. The heat developed in the two heat coils, was measured by a thermoelectric junction and a delicate galvanometer; one end of the junction was kept in melting ice, and the other end measured the heat of each coil in turn. The quantities of oil in the two were equal, so that the ratio of the galvanometer readings gave the ratio of the heat generated in the two.

We found it desirable to protect our lead-wires from air currents, and to pack the jars containing the heat coils.

The periodicity was measured by taking the speed of the alternator continuously during the test, it being necessary that the speed be constant, or nearly so.

The value of the coefficient of self-induction as measured by a large number of trials with Rayleigh's Bridge and the heat method compared as follows: —

Rayleigh's Bridge.	Heat Method.
.0157 henrys.	.0159 – .0164 henrys.

We then tested the effect of permeability and periodicity by putting an iron core into this same coil. The results were: —

$p = 629$	$L_1 = .066$ henrys.
$p = 1332$	$L_1 = .029$ "

These last results have to be considered with caution, as the impressed electromotive force is changed by changing the periodicity.

This gives an easy practical method of determining the coefficient of self-induction under the ordinary conditions of use, which, so far as we know, none of the various methods attempt to do. The method was suggested by Professor Trowbridge.

JEFFERSON PHYSICAL LABORATORY,
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